Karlsruhe Institute of Technology

Advanced modelling capabilities for pin-level subchannel analysis of PWR and VVER reactors

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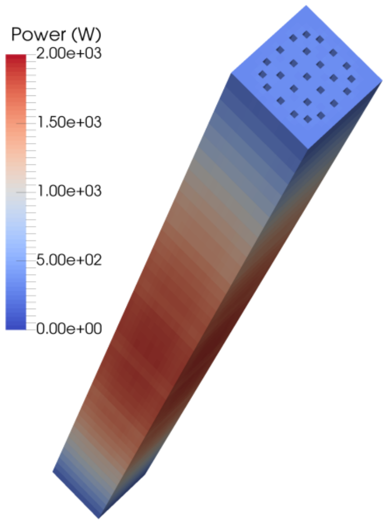

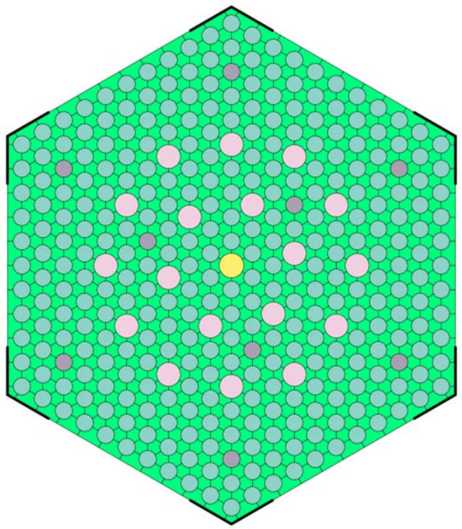

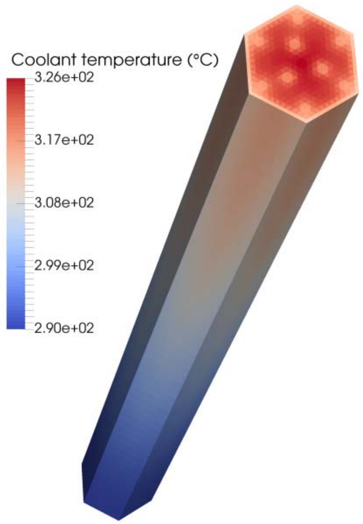

NURETH-18
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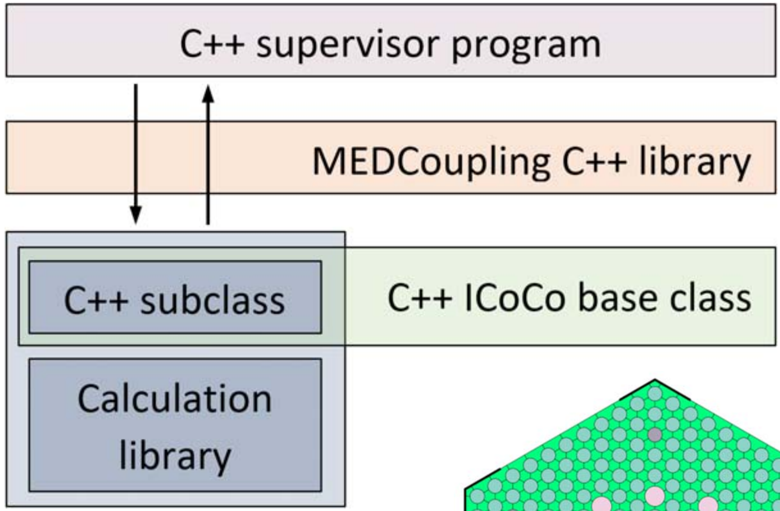
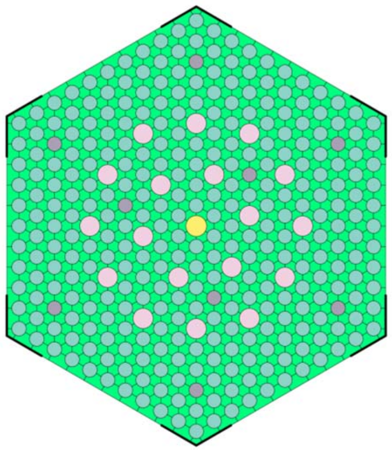
Introduction: the McSAFE EU project

- Objectives:
  - High-fidelity computational reactor physics:
    - Improvement of the prediction of local safety parameters.
    - Calculation of reference solution for low-order methods.
  - Development of multiphysics tools based on Monte Carlo particle transport, subchannel thermalhydraulics and fuel-performance analysis.
  - Solution of steady-state, depletion and transient problems.
  - Optimization for massive problems, e. g. full-core pin-by-pin burnup.
  - Validation with PWR (Konvoi) and VVER-1000 plant data.
- Participants:
  - KIT (SUBCHANFLOW).
  - VTT (Serpent2).
  - JRC, HZDR (TRANSURANUS).
  - CEA (Tripoli), DNC (MCNP), AMEC (MONK), NRI, KTH.
  - EKK, CEZ, EdF.
- Continuation of the NURESAFE and HPMC projects.

SUBCHANFLOW

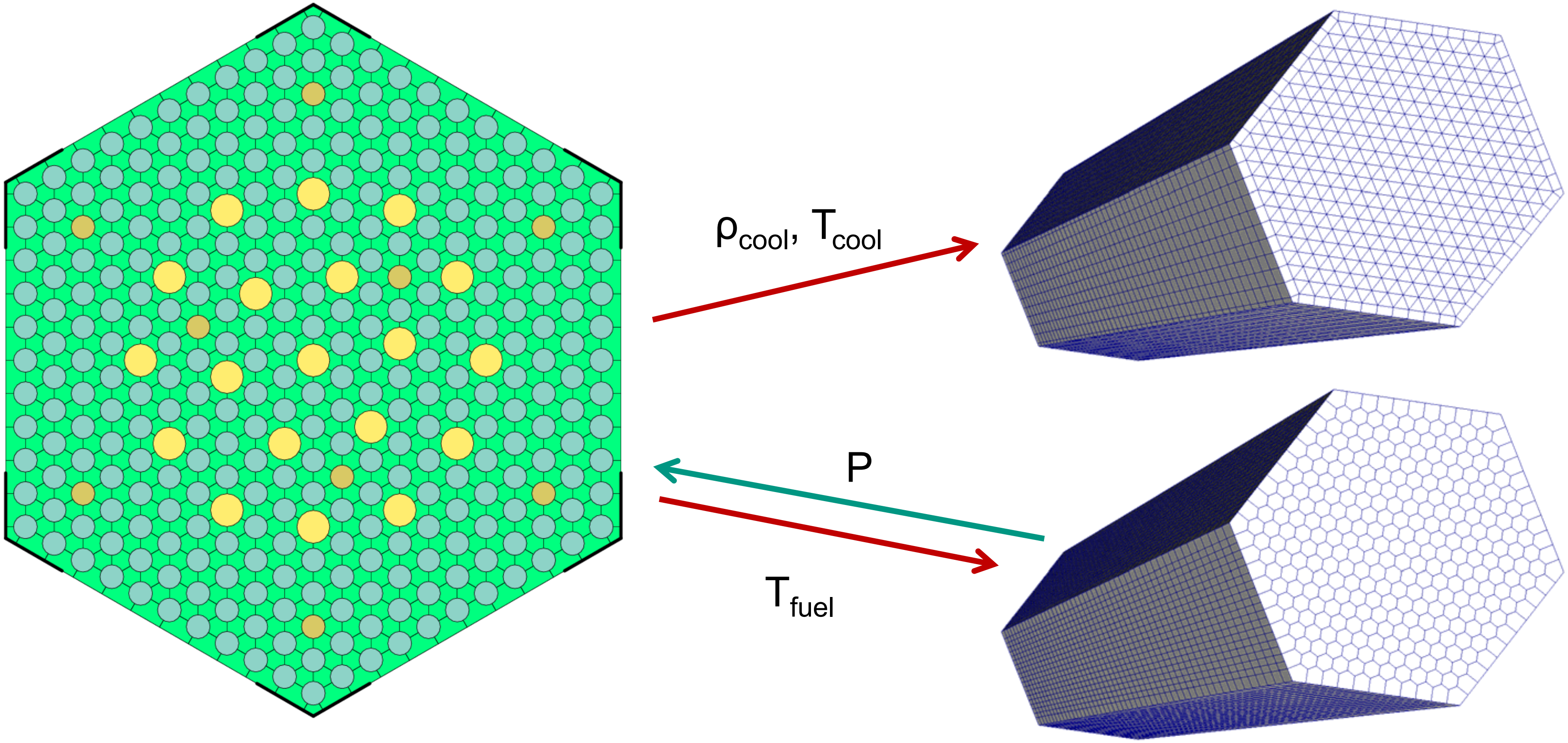
- COBRA- (MATRA-)based subchannel code developed at KIT:
  - Flow solver: 3+1 system of equations (mass, energy and momentum in the axial direction, plus a simplified lateral-momentum model for cross-flow).
  - Two-phase flow models (slip, saturated and subcooled void generation, etc).
  - Grid spacers and wire wraps.
  - Turbulent mixing.
- Multiphysics approach:
  - Calculation library.
  - C++ interface class.
  - Mesh-based feedback.
  - Object-oriented coupling.
- New preprocessor:
  - Subchannel model.
  - Structural components.
  - Unstructured mesh generation.





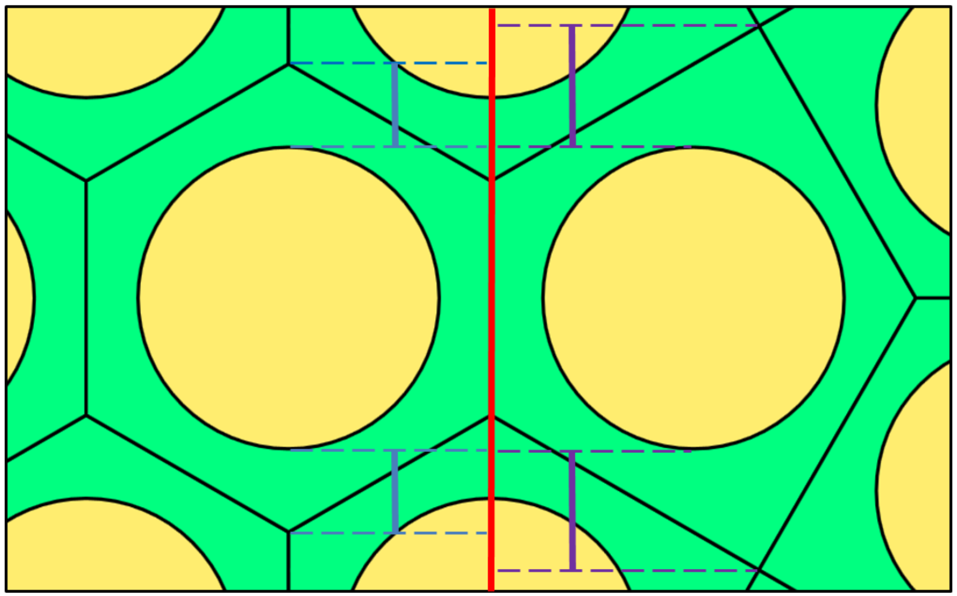
Mesh-based feedback exchange

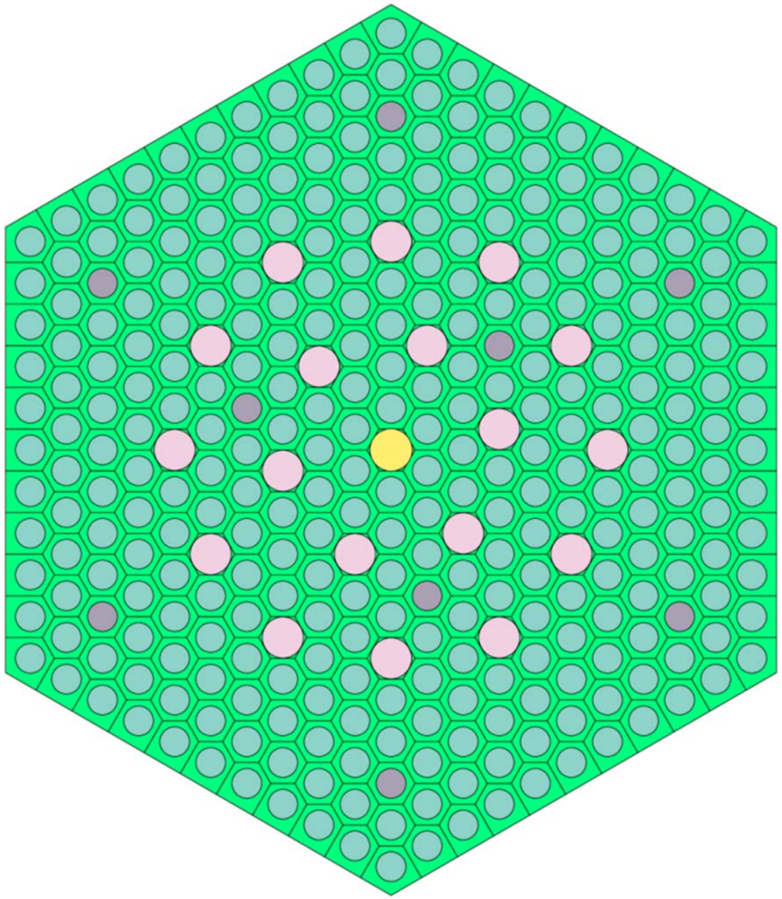
- Subchannel model defined by hydraulic parameters and connectivity.
- Coolant and fuel (MEDCoupling) unstructured meshes define the channel and rod geometry for feedback exchange and interpolation.



Subchannel models

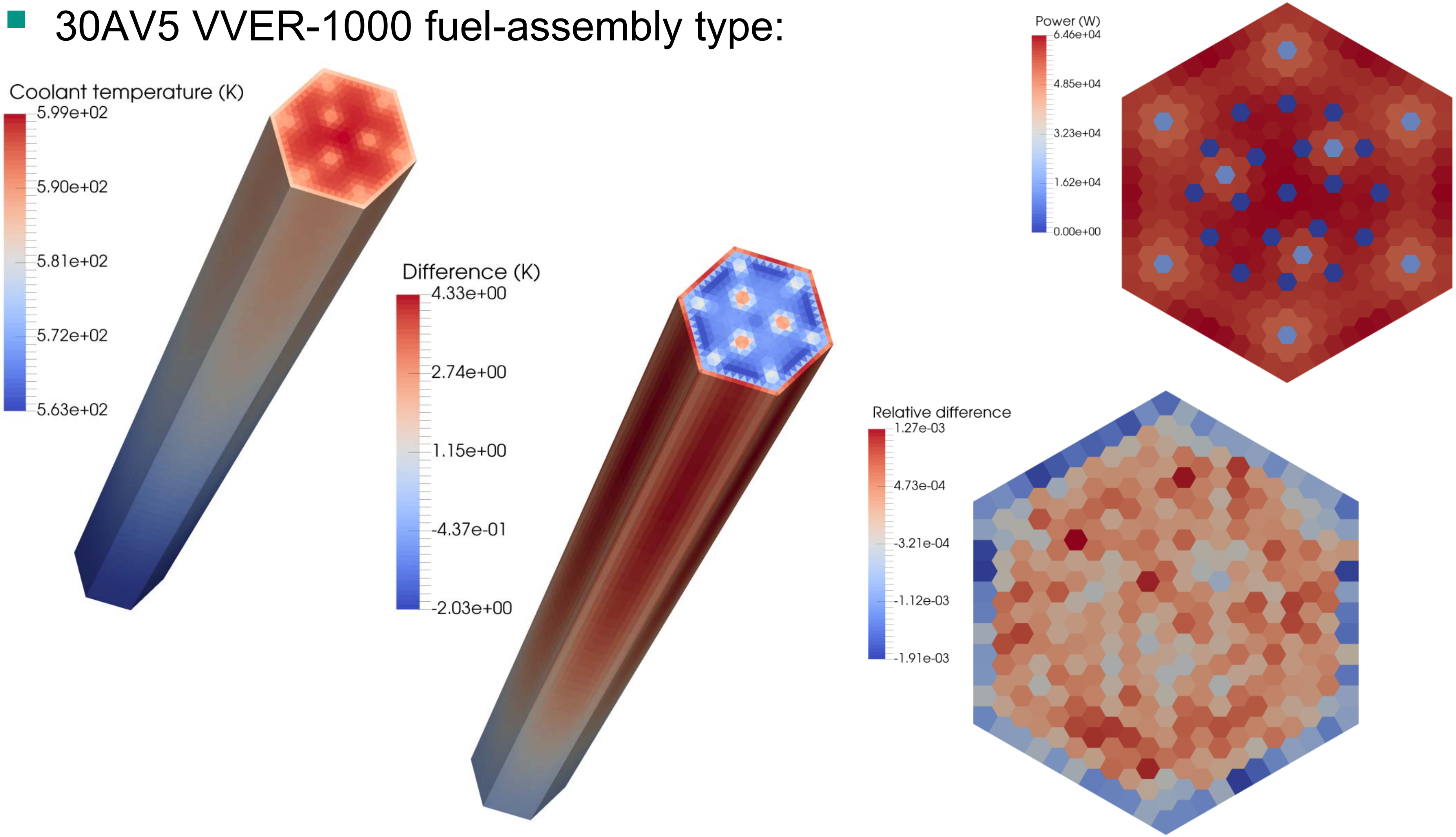
- Coolant-centered subchannels:
  - Widely used and physically sound.
  - Complex interpolation needed.
- Fuel-centered subchannels:
  - Parameters harder to define.
  - More convenient for multiphysics.





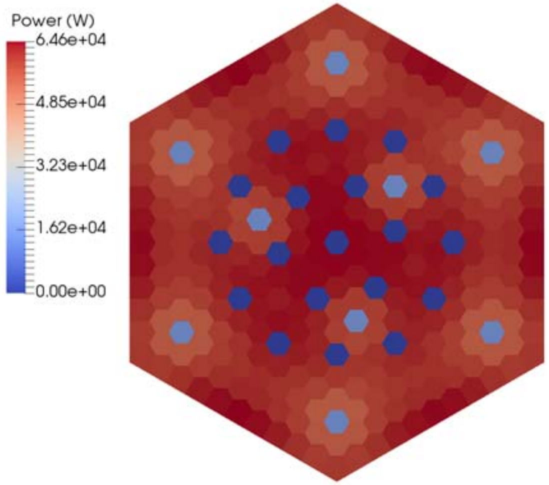
Fuel-centered subchannel models

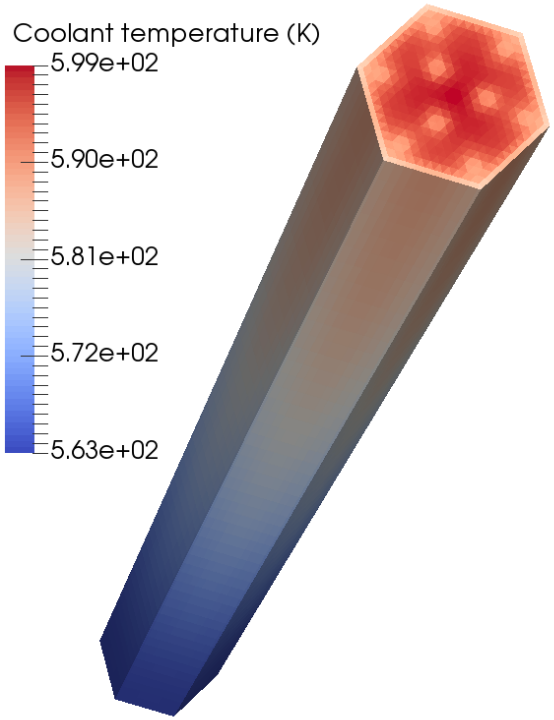
- 30AV5 VVER-1000 fuel-assembly type:

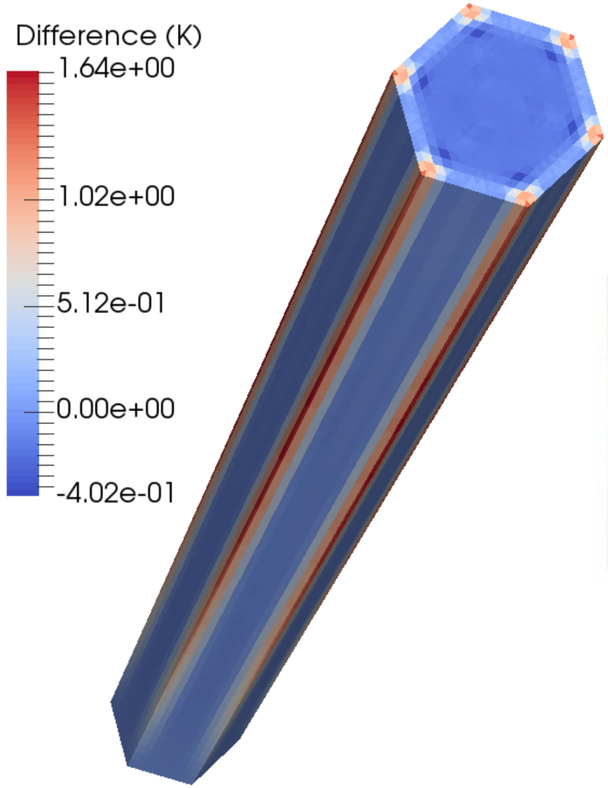


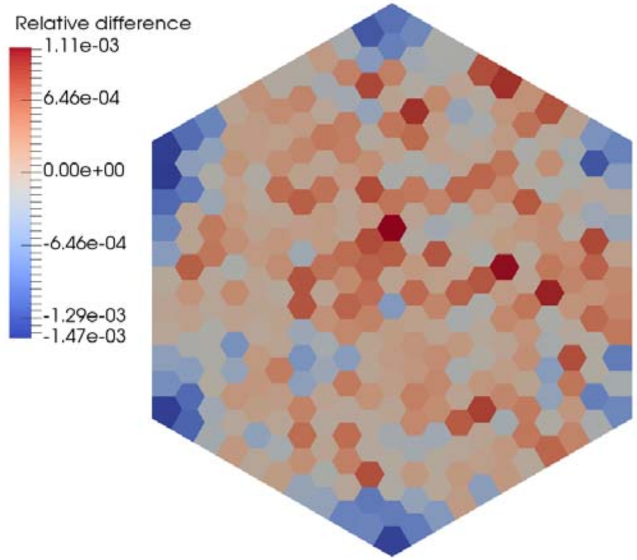
VVER-1000 stiffeners [1]

- Subchannel model:
  - Increased wetted perimeter.
  - Modified subchannel connections.
- 30AV5 VVER-1000 fuel-assembly type:





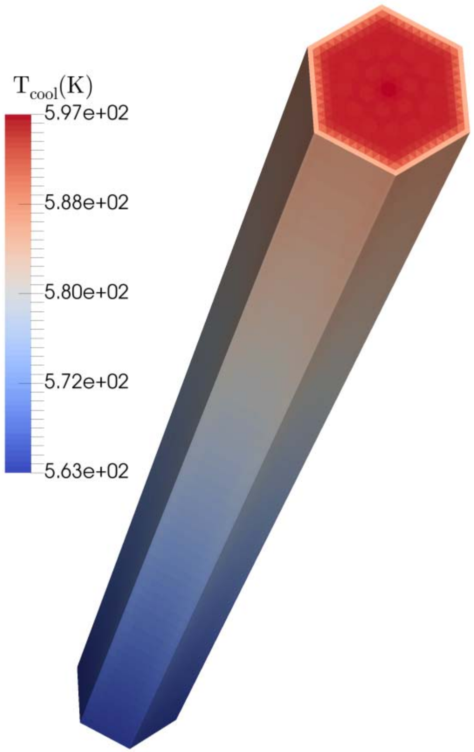


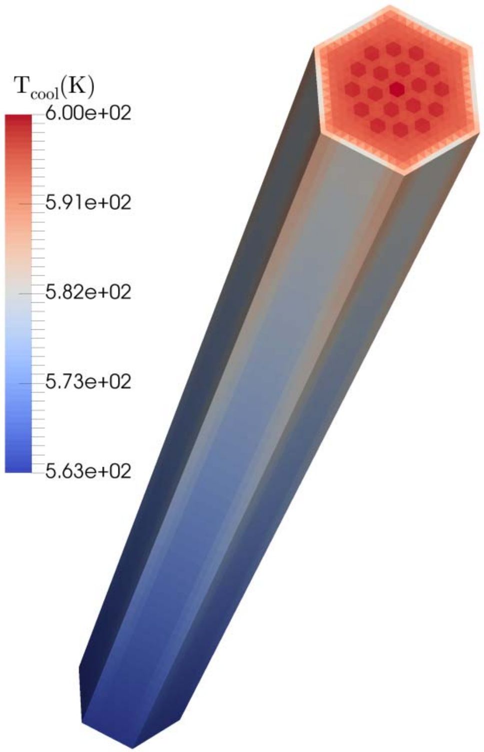


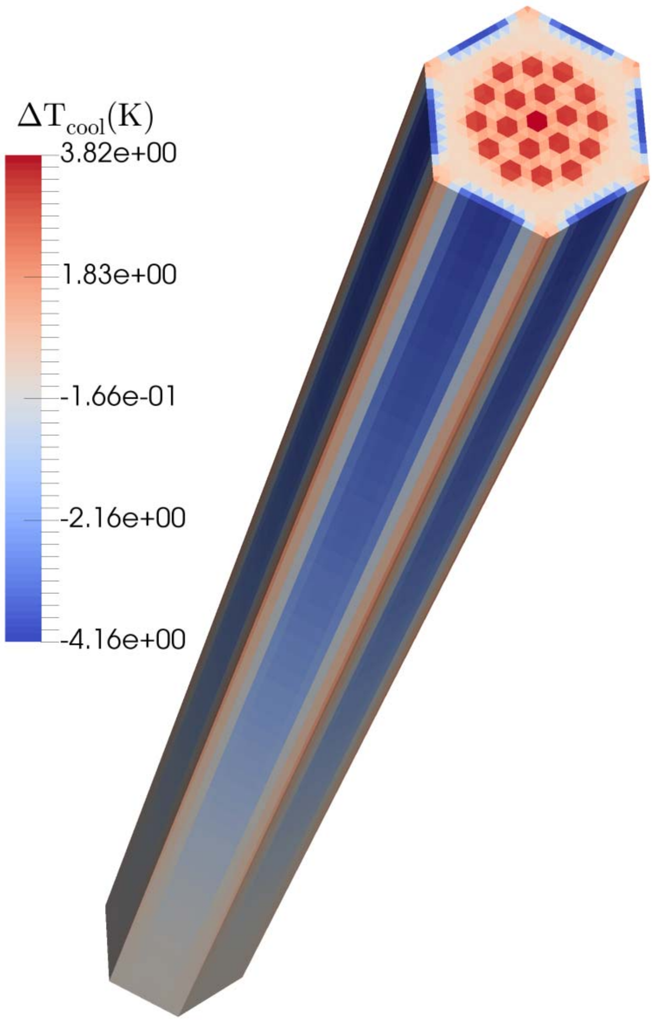
[1] "Serpent2-SUBCHANFLOW pin-by-pin modelling capabilities for VVER geometries". M. Garcia, D. Ferraro, et al. Annals of Nuclear Energy.

Cross-flow model

- Two phenomena:
  - Turbulent mixing.
  - Convective lateral flow.
- Pure-turbulent mixing much faster and stable.

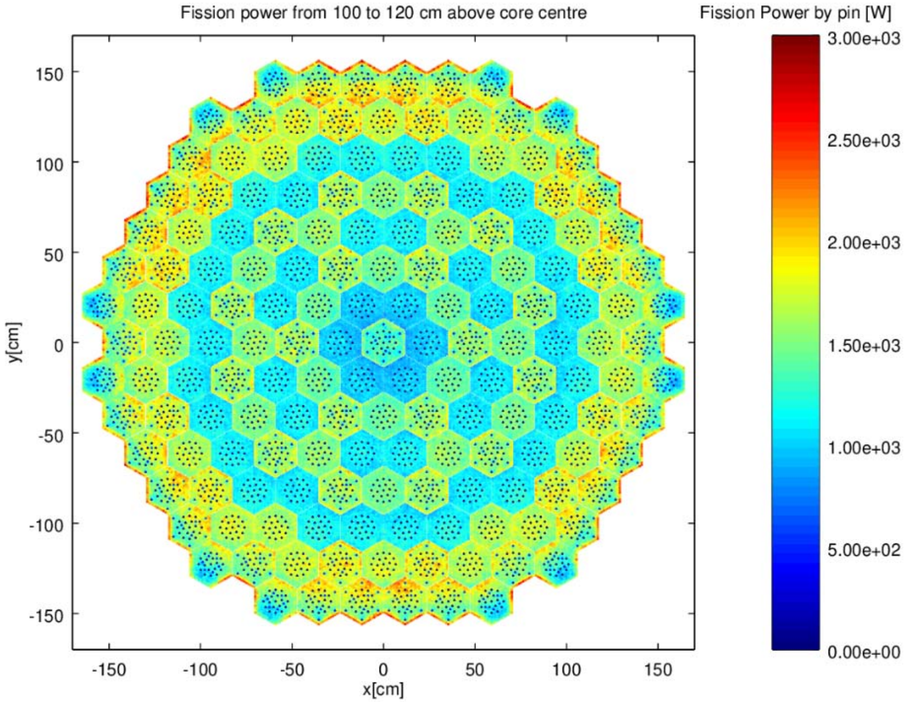


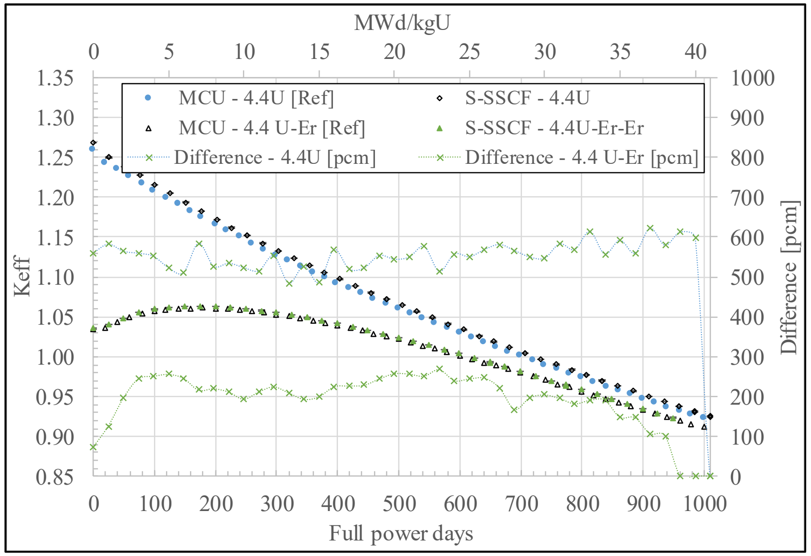




Applications: Serpent2-SCF [1]

- Current capabilities:
  - Steady state: full-core, pin-by-pin, fuel-assembly-level Xe.
  - Depletion: single fuel assemblies (memory bottleneck).
  - Transients: mini-core, pin-by-pin.
- Objective: full-core pin-level depletion.

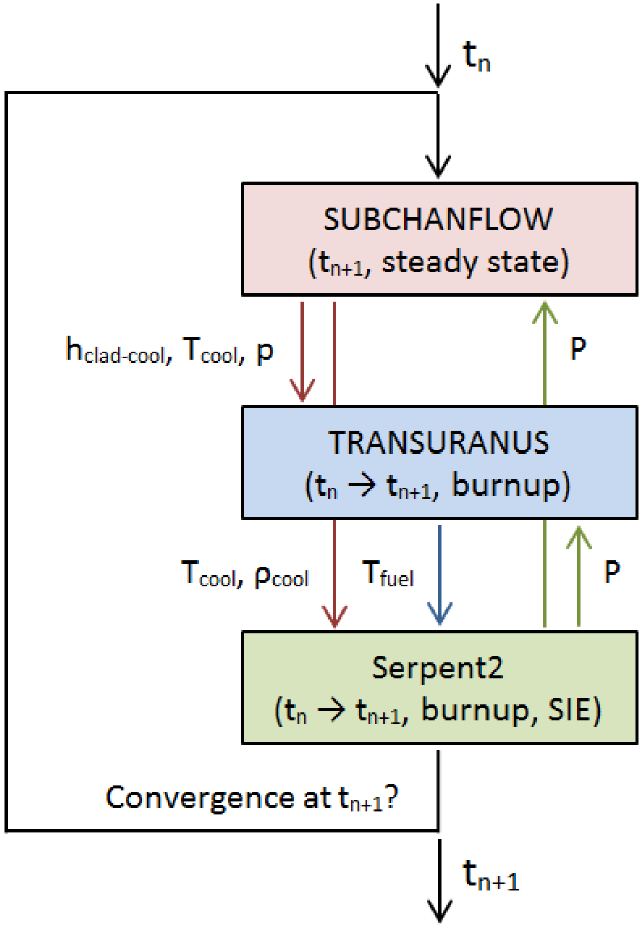


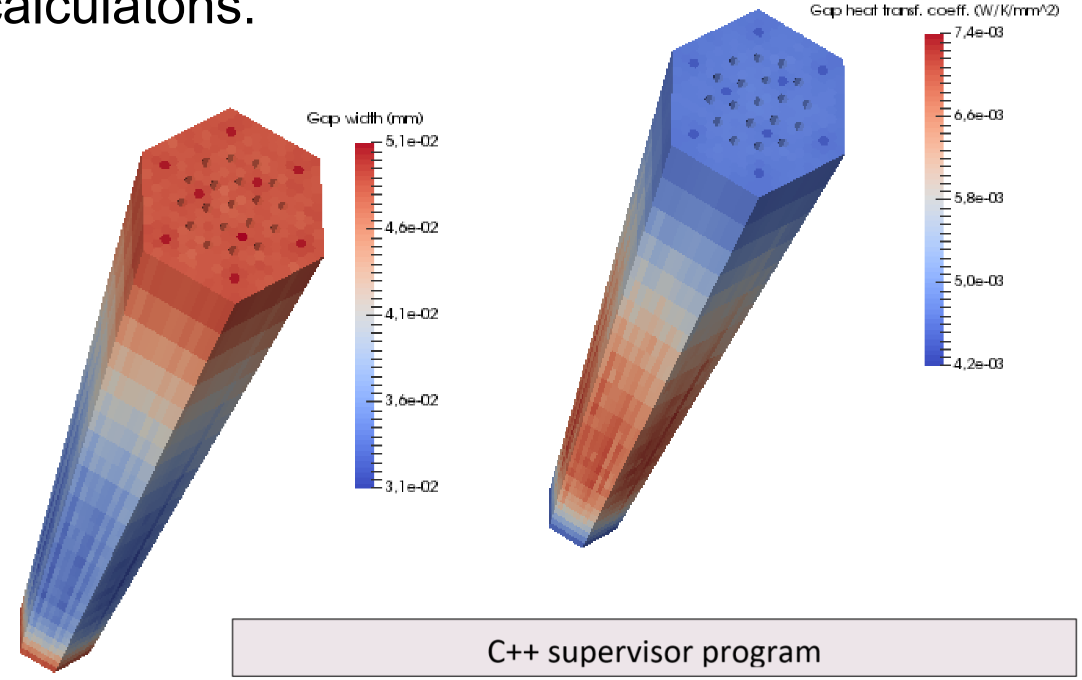


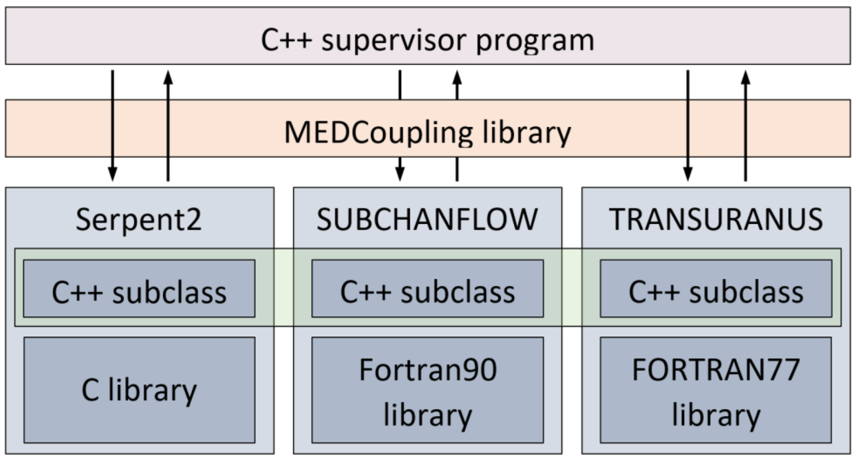
[1] "Development of an Object-oriented Serpent2-SUBCHANFLOW Coupling and Verification with Problem 6 of the VERA Core Physics Benchmark". M. García, D. Ferraro, et al. M&C2019.

Applications: Serpent2-SCF-TU [1]

- Steady-state and depletion calculatons.







[1] "A Serpent2-SUBCHANFLOW-TRANSURANUS coupling for pin-by-pin depletion calculations in Light Water Reactors". M. García, D. Ferraro, et al. Submitted to Annals of Nuclear Energy.

Conclusions

- SUBCHANFLOW multiphysics capabilities:
  - Object-oriented modularization.
  - Mesh-based feedback exchange.
  - New preprocessor for the generation of models.
- Analysis of subchannel models:
  - Coolant- and fuel-centered subchannels.
  - Explicit modelling of structural components.
  - Turbulent and convective cross-flow.
- Multiphysics applications:
  - Serpent2-SUBCHANFLOW for steady-state, depletion and transients.
  - Serpent2-SUBCHANFLOW-TRANSURANUS for burnup calculations.
- Further work:
  - Hot-channel methodology for full-core cases.
  - Optimization of coupled systems.
  - Validation with plant data for depletion calculations.


THANK
YOU
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NUHUN
SPASSIBO
SNACHALHUYA
SUKSAMA
EKHMET
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MAITEKA
YUSPAGARATAM
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